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13 Jun 2019 10:05:40

8th International Conference on Fog, Fog Collection and Dew
Taipei, Taiwan, 14–19 July 2019
IFDA2019-10

A Brief Overview of Sea Fog Research in China during the Past 40 Years

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Sea fog is one kind of weather phenomena occurred widely over oceans and coastal regions wherein tiny water/ice droplets sustained in the atmospheric boundary layer and caused the horizontal atmospheric visibility to be less than 1000 m. A large number of previous studies have indicated that Bohai Sea, Yellow Sea and East China Sea were the most frequent sea fog occurrence areas in the world. The low atmospheric visibility associated with sea fog is a serious threat to the safety of ship navigation. According to the statistics of the China Maritime Safety Administration in Zhoushan, Zhejiang Province, over 70% of the marine accidents such as ship-collision or stranding that occurred at sea were caused by the sea fog. When sea fog occurs, it not only affects the maritime navigation and harbor operations, but also causes coastal high-way transportation to be blocked or even closed. As sea fog is a great threat to coastal high-way transportation, fishing, harbor operation, and electricity power transportation, thus, understanding of sea fog is of both scientific and practical importance.

This talk aims to make a brief overview of sea fog research in China over the past 40 years. The main purposes are twofold: the first one is to briefly summarize the sea fog research in China, and the second one is to look forward to the future development of sea fog research. Some important issues such as academic books and dissertations related to fogs, microphysics of sea fog, numerical simulation, data assimilation and ensemble prediction of sea fog in China were focus. This talk may provide useful information for those who concerns with the progresses of sea fog research in China.

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A hybrid satellite fog retrieval scheme and climatology using machine learning

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We introduce a novel hybrid approach for fog retrieval based on Meteosat Second Generation (MSG) and ground truth data. The method is based on a random forest (RF) machine learning model that is trained with cloud base altitude (CBA) observations from Meteorological Aviation Routine Weather Reports (METAR) and synoptic weather observations (SYNOP). Cross validation results show good accordance with observation data with an average Heidke Skill Score of 0.58 for fog occurrence. Using this technique, a 10 year baseline fog climatology with a temporal resolution of 15 minutes was derived for Europe for the period from 2006 to 2015. A temporally highly resoluted and spatially explicit analysis of variations in fog occurrence was conducted for Europe on the basis of this data set. Characteristic fog patterns were identified by applying a Self Organizing Map approach onto the data set. It was found that the resulting fog patterns are primarily determined by terrain characteristics. Correlations between these patterns and the predominant general weather situations were computed and analyzed. This analysis showed that the general weather situations can be categorized into three main groups, each responsible for the formation of a different group of fog patterns. Additionally, distinct regional differences could be identified in the diurnal and annual fog frequency cycles and the derived region-specific frequency variations were used to draw conclusions about the fog types prevailing in these regions. The presentation will include to the new technique and will particularly focus on the spatio-temporal fog pattern during different weather types.

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The boundary layer character of spring sea fog inland penetration over the coastal area of Qingdao

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Sea fog refers to the fog that takes place under the oceanic effects and occurs worldwide, including over open sea and coastal areas. Sea fog sometimes penetrates inland, the low visibility will influence on traffic along the coast or on the bridge and aircraft landing, leading to insecurity and economic loss. On the other hand, sea fog inland penetration brings liquid water vapor to land and benefits terrestrial ecosystems in the coastal arid and desert regions. Therefore, understanding and predicting this phenomenon, which we term as sea fog penetration (SFP) hereinafter, is important for human activity and ecosystem over the coastal regions. The sea fog could be directly transported into land by sea breeze especially, which is caused by land warming during daytime. Besides, the land warming increases temperature and atmospheric instability and decreases relative humidity (RH), preventing sea fog from maintaining on land and marching inland from the coast.

Yellow Sea is a foggy area particularly in spring, where about 80%-90% of sea fog belongs to advection fog (Wang 1985). Many previous studies investigate the mechanisms for formation, continuation and dissipation of sea fog here (Gao et al. 2007, Zhang et al. 2009, 2012, Heo and Ha 2010, Kim and Yum 2010). Sometimes sea fog would penetrate inland over tens of kilometers (Jiang et al. 2008), covering nearly half of Qingdao region and affecting inland traffic safety seriously. Yet only a few studies focus on the SFP. Even Sun et at. (2017) found that the one with warmer and moister advection, in conjunction with intensified radiative cooling effect at fog-top can move into land farther, compared two springtime SFP events in Qingdao. However, we do not know either the statistically characteristics or the climatological characteristics associated with different intensity of SFP.

The present study uses observations of automatic weather stations (AUWES) to detect the inland penetration of sea fog, combined with several sets of observation and reanalysis, to quantitatively analyze the general features and preferable climatological boundary layer conditions of SFP. Our investigation wish to address the question that what is the key factor related to the intensity of springtime SFP in Qingdao? The results emphasize the humidifying, rather than cooling, plays a crucial role in the initial process of springtime SFP in Qingdao coastal region. This work promotes the forecast of SFP and helps to advance the knowledge of the SFP mechanism.

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A Comprehensive Observational Overview of Dutch Fog

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The Netherlands is characterized by highly variable land use and industry, with dense cities surrounded by agricultural regions, and a strong influence of the North Sea on national climate. Yet, it is devoid of significant topography, making it an excellent location for assessing the relative influence of regional land use variability on fog occurrence, in the absence of complex terrain effects.

The climatology of fog in the Netherlands is assessed over a period of 45 years using observations from a dense network of weather stations throughout the country. Overall fog occurrence and interannual variability are assessed. On a national scale, interannual variability is linked to large-scale synoptic pressure forcing, including changes in the strength and position of the Icelandic Low/North Atlantic Oscillation. Within the country, a comprehensive in-depth analysis of regional differences between fog occurrence is made, together with an assessment of local physical factors that could bias fog formation in one location over the other. Regional variability in local fog climatology is shown to be strongly related to the mesoscale influences of urbanization and the North Sea, with some locations found to experience over twice as much fog as others. From this finding, a simple and robust fog index was distilled, which combines the water and urban fraction surrounding a station, and is proposed for practical use. The index is extensively tested and able to accurately sort the stations according to their relative fogginess. Such an index can be used to assess a site's climatological favourability for fog formation, without the need for any a priori meteorological observations.

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Fog, temperature, and air quality over the Metropolitan Area of São Paulo: A trend analysis from 1998 through 2018

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Many meteorological stations worldwide show a decrease of the intensity and density of fog. It has been hypothesized that both climate change, i.e. an increase of the air temperature, as well as an increase of air quality, i.e. a decrease of gaseous air pollutants and the number concentration of hygroscopic aerosol particles, are drivers of the decrease of fog. We analyse very long time series from the Metropolitan Area of São Paulo (MASP) in order to test this hypothesis. Daily fog data since 1933, from Fonte do Ipiranga Weather Station, including all other meteorological data, indicates an overall decrease of fog days, although some very fog-intense years are documented for 1976 (193 days), 1977 (212 days), and 1978 (207 days). In 2018, only 59 foggy days are documented. Since 1998, PM10 (mass concentration of particulate material with aerodynamic diameters below 10 μm), SO_2, and NO_x data are available from CETESB (São Paulo Air Pollution Agency). Unfortunately, a continuous time series of PM2.5 concentrations exists only since 2011. We focus our analysis to the 21-year period, 1998 – 2018, which presents continuous records of temperature, humidity, air pressure, PM10, SO_2, and NO_x concentrations. A strong decrease of the number of foggy days has been documented for this recent period of investigation. Synchronously, air temperature increased and the PM10, SO_2, and NO_x concentrations decreased. We apply a logistic regression analysis for the identification of trends and for analysing the regressions between the occurrence of fog on the one hand and temperature and air quality parameters on the other. Detailed results will be presented.

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Weakening of Asian monsoon, not cloud cover change, determines the climatic variability in montane cloud forest

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Tropical montane cloud forests (TMCF) are unique ecosystems characterized by frequent cloud immersion. Stable hydroclimate maintains a high level of species endemism and regulates water resource far beyond the geographic extents of TMCF. So far, vulnerability assessment of TMCF has focused on the changes of cloud behavior and its impacts on the stability of hydroclimates. However, large-scale climate driver, such as monsoon may interact with local clouds to mediate climatic variability. In montane cloud forests in Taiwan, the cloud cover kept decreasing since 1950s, but annual temperature variability (TAR) was also reduced. Increasing minimum temperature in the coldest season and decreasing maximum temperature in the warmest season both contributed to the reducing TAR. We found that temperature in the coldest season was mainly mediated by winter monsoon, while the cloud cover has limited direct effect. Temperature in the hottest season was largely determined by precipitation, which was influenced by summer monsoon without the effect of cloud cover change. As such, the change of monsoon system, not cloud cover, dominates climatic variability in montane cloud forest. We applied multiple dendroclimatic proxies to reconstruct local climates for the past 480 years (AD 1533-2012). The dynamics of cloud cover are within the range of long term fluctuation. However, the magnitude of warming in the cold season has never been observed for the past half millennium. We provided the first cloud reconstruction in Asian montane cloud forest where the weakening of prevailing monsoon systems has led to a warmer but less variable climate regime.

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The importance of in-situ processes and advection impacting radiation fog at orographically contrasting locations.

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The Local and Non-Local Fog (LANFEX) experiment has provided highly detailed observational data over an 18-month period. The LANFEX campaign took place in the UK in two different locations. One, an inhomogeneous complex valley system with valley to hill heights of 100 – 150m and valley widths of around 1 - 4km; the other a more homogenous area with a wide shallow valley of width around 10km and height difference 30-40m. Orography is known to have an important role on the life-cycle of fog events with cold pools and the associated drainage flows also occurring on clear sky nights ideal for fog formation. One key aim of the LANFEX campaign was to elucidate the relative importance of in-situ and advective processes have during the life-cycle of fog events including its formation, vertical development, including the stability of the boundary layer, and dissipation. Combining the LANFEX observations and a sub-kilometre scale version of the UK Met Office's Unified Model, which resolves the orography at both LANFEX sites, two case studies, one at each site, have been used to investigate the relative importance of different processes. Using the sub-kilometre scale model, the temperature and liquid water budgets within the model have been used to quantify the relative magnitude of the processes involved during the events. A comparison of these budgets at different sites within the two LANFEX locations have highlighted the impact of valley geometry and the difference in the relative importance of processes between hill and valley areas at various stages during a fog event.

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Effects of orographically induced low-level moisture convergence and inversion strength on upslope fog: a case study at Xitou

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Montane cloud forest (MCF) is characterized by forest which is frequently immersed in clouds or fog so that the interception of cloud/fog water provides extra hydrological input to this ecosystem. Previous studies suggest that under global warming scenario, the rise of cloud base height could leads to an upward shift of MCF. This impact could lead to the shrinking and fragmentation of MCF over complex topography such as Taiwan, a subtropical island with more than 200 peaks and the elevations ranging from sea level to nearly 4,000 m. Previous studies of MCF in Taiwan is merely focusing on the dynamic and thermodynamic processes of the fog formation. In this study we examine the effects of orographically induced moisture convergence and the processes of fog formation at Xitou valley of Taiwan by ceilometer observation and idealized large eddy simulations. This is the first attempt to understand the local circulation associated with fog at Xitou using a high-resolution cloud-resolving model. Observation analysis shows that the ceilometer is not only reliable to detect fog occurrence but also provides more information about low-level cloud base evolutions. In a fog case on Jan. 7th, 2016, the low-level cloud base lowering is observed before ground fog formation, which is also associated with the valley winds at Xitou valley as previous studies mentioned. To understand the processes of the moisture transport associated with the fog formation, idealized simulations using high-resolution vector vorticity equation cloud-resolving model (VVM) with realistic land surface processes are performed to evaluate the local circulation associated with the fog development. The results indicate that both the upslope winds and the turbulent eddies at the edge of the upslope winds are primary local processes to moisten the boundary layer in the valley which leads to fog formation at Xitou. Sensitivity experiments on inversion strengths show that local fog duration is also controlled by synoptic inversion strength. The results show that the effects of orographically induced low-level moisture convergence are the essential processes to supply moisture in the Xitou valley, and the capping inversion helps the ground fog formation by limiting the development of convections and preserve moisture in the valley. With stronger capping inversion above Xitou valley, the moisture is trapped in the valley, and the fog duration is consequently longer.

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Linking interannual and interdecadal fog variability in Atlantic Canada to changes in large-scale atmospheric and marine features

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The main formation mechanism of marine and coastal fog is the cooling of warm and moist air advected over a colder sea surface. The proximity of cold and warm water currents that provides the required contrast makes Atlantic Canada one of the foggiest regions of the world. The frequent resulting low visibility notably disrupts off-shore operations and marine traffic, but also land and air transportation. On longer time-scales, fog can also impact agriculture, insect-borne disease transmission and the global radiative budget. Clouds, including fog, are the greatest source of uncertainty in the current climate projections because of their complex feedback mechanisms. Meteorological records indicate that the occurrence of foggy conditions has been decreasing over the past six decades at most airports in Atlantic Canada, with large internal variability, including interannual and interdecadal variations. Using the airport observations, reanalysis data and climate model outputs, we investigated the various variabilities on the trend, at interannual and interdecadal scales, and attempted to address what caused these changes in fog frequency. Our analyses revealed that the strength and position of the North Atlantic Subtropical High as well as the sea-surface temperature of the cold and warm waters near Atlantic Canada were highly correlated with fog occurrence. In addition, we used the method to predict fog with the current climate model output and project the trends and variability in the different future climate scenarios. The results from this study will be compared with those obtained from other prediction methods and their implications will be discussed.

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GOFOS, Ground Optical Fog Observation System for monitoring the vertical stratocumulus dynamic in the coastal Atacama Desert, Chile

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The vertical variability of the stratocumulus (Sc) cloud in the interface ocean-land at the coastal Atacama Desert ($\sim$20°S) has been well described, but in its interaction with the local topography it has been roughly characterized, conditioning our understanding of the atmospheric conditions under which the fog occurs. Our aim is to analyze and characterize the vertical variability of fog at a local scale and the vertical structure of atmospheric boundary layer (ABL) by using a Ground Optical Fog Observation System (GOFOS). A database every 10 minutes by the year 2017 is obtained from GOFOS, which is based in two time lapse cameras located at altitudes that regularly lie above the thermal inversion layer and under the lower cloud base altitude respectively, and observing an altitudinal profile of autonomous LED solar lights allowed to characterize the fog vertical variability. These measurements are validated by using a transect of weather stations located at 50, 750 and 1.200 m a.s.l to determine the ABL regimes established by Lobos et al (2018). The GOFOS measurements are compared with the ABL regimes which estimate the fog presence-dissipation through a well-mixed/stratified regime. We characterize the daily, monthly and seasonally fog cloud top (CT), cloud base (CB) and cloud depth (CD). The CT, CB and CD, show marked seasonal and daily variations. In addition, the altitudes and depths are inversely related with the fog frequency presence (FFP). The highest CT and CB altitude occur during summer ($\sim$1.230 and 970 m a.s.l. respectively). Summer also record, the thickest CD ($\sim$315 m) when the FFP is at its minimum (seasonal mean of $\sim$3,5 %). The CT and CB reach their minimum mean altitude in winter ($\sim$1.040 and 850 m a.s.l., respectively), as well the thinnest CD ($\sim$220 m), this season coinciding with the maximum FFP ($\sim$50 %). From a daily perspective, the relation between cloud altitude and depth with FFP is also inverse, with maximum CT, CB and CW during the afternoon and minimum during night-dawn. In presence of fog, the ABL is well-mixed and the proposed regimes of specific humidity(q) agree above 90%, while the potential temperature (θ) reaches 70%. Summer and daylight time shows a deep ABL, which is related to a high stratification within the ABL, thus lower FFP, oppositely, during winter and night-dawn the ABL is shallower and under well-mixed conditions, thus higher FFP. The new fog monitoring system (GOFOS) allow us to characterize accurately the vertical fog variability at coastal Atacama Desert, as well as to validate and adjust the atmospheric regimes proposed, both key indicators for future fog harvesting forecast.

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Fog Collection along Coastal California from San Diego to Arcata

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For the past 10 years an array of standard passive fog collectors along coastal California has been gradually changing and expanding as new sites come online for the purpose of monitoring spatial and temporal fog variability along the Western Coast of California, USA. Beginning with one site near Monterey, CA in 2009, fog collectors have gradually been added to other sites both north and south of the initial sites in Monterey and represent an irregularly-spaced grid of standard fog collector measurements at over two dozen sites scattered within the coastal region and spanning a distance of over 1200 km. This paper examines some of the trends associated with data collected from this array during the past decade. Of note is the significant spatial variability at hourly (and finer) time scales even between fog collectors at relatively closely-spaced sites. Additionally, differences associated with elevation and distance from the coast are examined.

Of further interest are the significant reductions in fog events at some near-sea level elevations during the typically foggy late summer in 2014 and 2015. Such trends will also be examined at other sites and at other years at various locations that exhibit a diversity of elevations, latitudes and distances from the coastline.

We have also recently deployed a pair of fog collectors at Fray Jorge National Park in central-northern Chile, significantly extending the size of our previous footprint. Recent data collected from this site will be compared to data from northern hemisphere locations on fine timescales to note any distinctions in the collection rates during typical fog events.

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Examples of rime and hoarfrost threats for human activity in the Western Sudetes, Poland

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Rime is formed as a result of freezing of supercooled droplets of fog on objects, whose surface temperature is below or equals zero. Rime takes the form of an icy precipitate resembling feathers which forms on the windward side of all objects protruding from the surface (e.g. trees branches, rocks). The most favourable conditions for the formation of hoarfrost occur when Poland is in the central part of an anticyclonic situation. Then, the dominating macroscale processes of air subsidence are conducive to cloudless weather with very weak wind. Hoarfrost forms when water vapor changes directly into solid ice.

The aim of the study is to draw attention to rime and hoarfrost as the reasons for the occurrence of selected threats: (1) rime considered as the factor leading to damages taking place in forests and various types of constructions (even buildings) through the weight of rime and glazed ice; (2) layers of surface hoarfrost or rime as a weak layer in the snowpack leading to an avalanche desent.

The largest direct and destructive role of deposit from fog to forest ecosystems occurs at sub-zero air temperature. The total weight of the load of ice in the case of a single tree can reach up to 2000 kilograms. This is backed by the results of rime efficiency measurements on so called Grunow collector. On mountain ridges in the Western Sudetes, atmospheric damage to the forest stand includes 16.4% of the surface. The most spectacular example of the threat posed by the load of rime is the construction disaster that affected in March 2009 the Meteorological Observatory building, located at the Śnieżka summit, at 1,602 metres above the sea level.

At steep slopes where hoarfrost is deposited on the surface of existing snowpack, particularly where the intensity of incoming solar radiation is low and preserves the snow from melting, hoarfrost may become a “weak layer” in the process of snow avalanche triggering. An avalanche accident of such type on the northern slopes of the Western Sudetes is also presented in this paper.